

# Fabrication of Structures/Relationship with Suppliers

- **The devices for test will be obtained from companies to ensure consistent state-of-the-art material quality and device design.**
- **Nitronex**-GaN HEMTs on Si, before and after dc aging. Perform rf stressing and characterization of the devices with our suite of techniques. Nitronex may also supply bare wafers, for calibration and to allow us to make some large area diodes and capacitors that can be aged and will provide a simpler initial characterization vehicle (Wayne Johnson and Ed Piner).
- **Raytheon**- possibly InP and GaAs HEMTs on Si and InP HBTs on Si produced for the DARPA COSMOS program. GaN HEMTs on SiC substrates. Provide stressed and unstressed samples that will allow us to characterize the differences induced by rf and dc stressing and begin to identify the underlying physical mechanisms (Kurt Smith and Jeff LaRoche)
- **WIN Semiconductor**- will supply GaAs pHEMTs for stressing and characterization. Initially we will purchase these devices, but may enter into a more collaborative arrangement as the program proceeds.
- **RFMD**-a range of their device codes (Mike Antonell, Curt Barratt and John Fendrich)
- **Intel**-Reliability statistics support, compound devices on Si
- As the program progresses, we can add additional suppliers. We have former students and colleagues working at virtually all the compound and elemental semiconductor companies in the US and can readily tap into this network. We have a complete device fabrication/testing capability at UF including e-beam lithography through to rf and power testing. There will be a limited number of occasions where specific test structures or different metalizations will be required to provide additional evidence on the degradation mechanisms and we can provide these in-house.

# Observations on Compound Device Reliability History-Roesch 2006

- A quick look at the global reliability data for compound devices shows no obvious improvement in 20 years
- Is this an indictment of our industry or the fact we have always been moving to the “next” device technology?

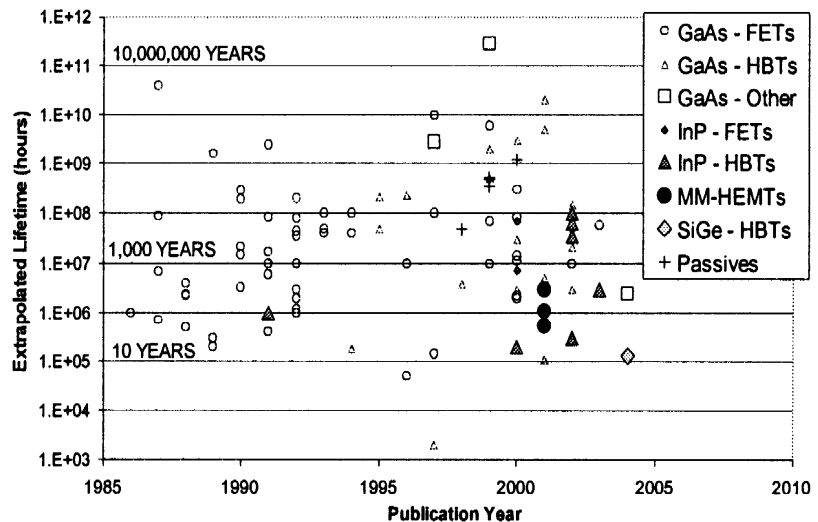


FIGURE 1. REPORTED OPERATING LIFETIMES FOR VARIOUS COMPOUND SEMICONDUCTORS OVER THE 19 YEAR HISTORY OF THE ROCS WORKSHOP<sup>[1]</sup>

# Observations on Compound Device Reliability History-Roesch 2006

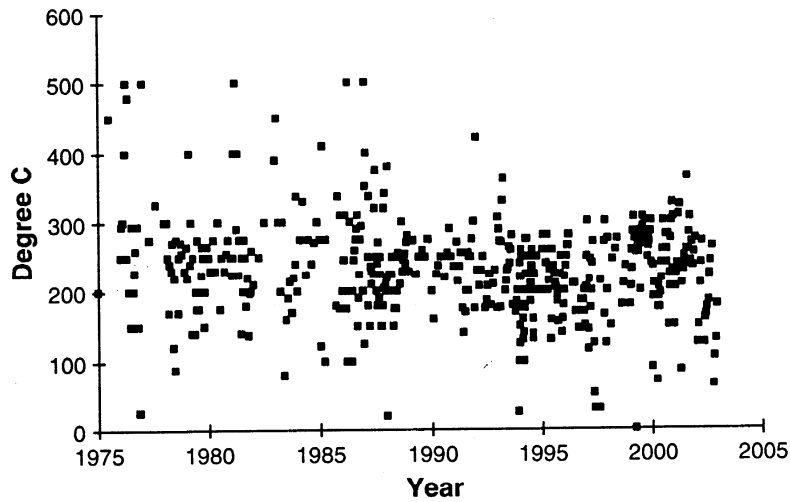


Fig. 8. Reported accelerated test temperatures.

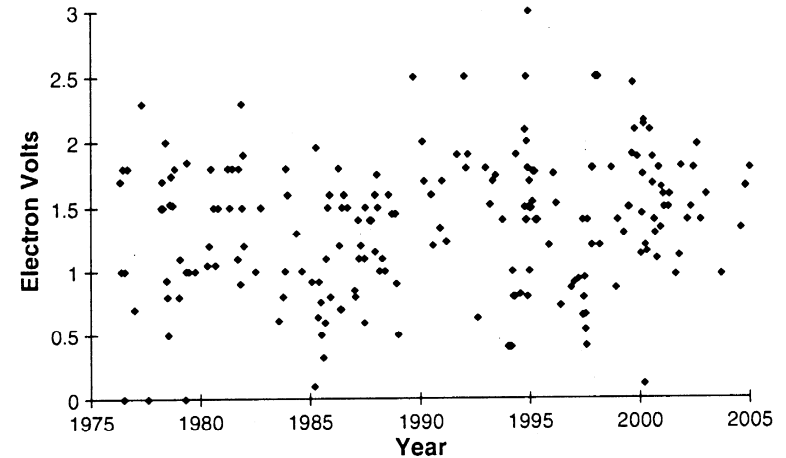


Fig. 10. Reported activation energies.

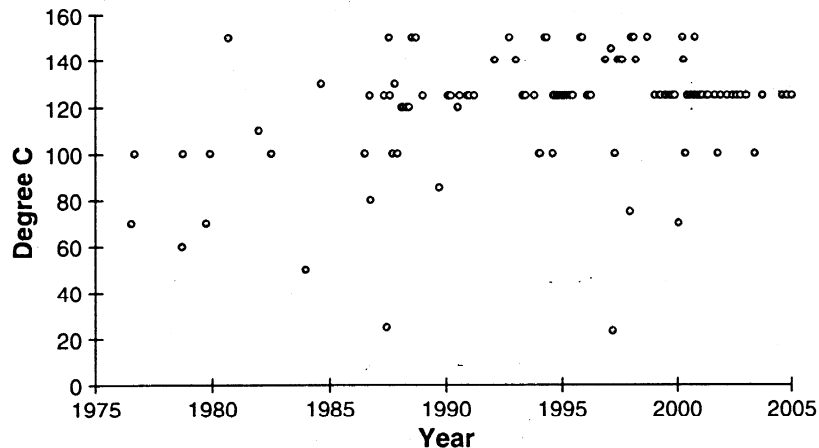


Fig. 9. Reported temperature of operation (use temperature).

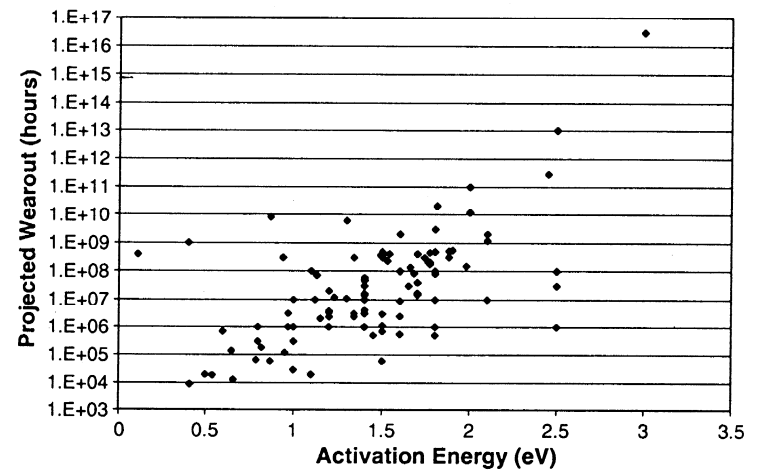
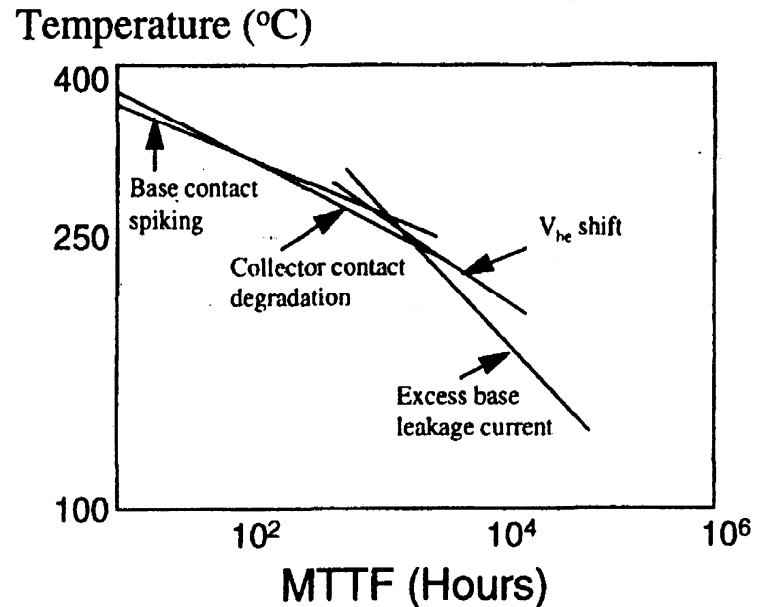


Fig. 11. Relationship of lifetimes to activation energies for reported compound semiconductor reliability studies.

# Temperature Acceleration of Degradation-example from GaAs-based HBT reliability

- $\ln(t_1/t_2) = E_a/k(1/T_1 - 1/T_2)$ , where  $t_{1,2}$  are time to failure at temps  $T_{1,2}$
- This slide from Triquint highlights the problem of using temperature acceleration as the only reliability test (Henderson, Reliability of Compound Semiconductors, 2006)
- This seems to be generally understood and there is increasing use of voltage, current and rf stressing at temperatures closer to the actual device operating temp (field returns due to other factors, ESD, capacitor defects, assembly/package issues)
- 2000 GaAs Rel. Workshop in Seattle- 9/10 papers used accelerated temp as the sole basis of predicting reliability (Roesch, Micro. Rel. 41, 1123 (2001))



# GaAs-based HBT reliability

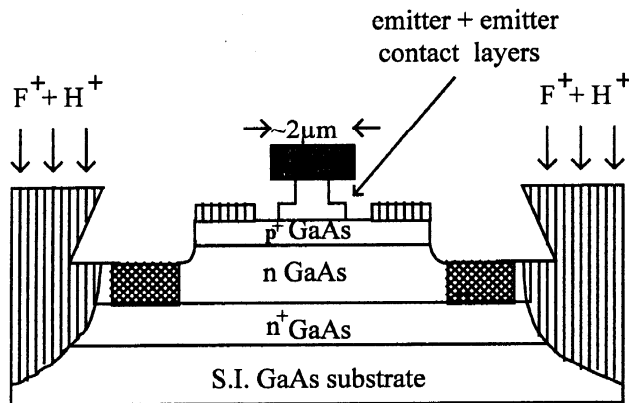
- C replaced Be, Zn as base dopant
- AlGaAs→InGaP(surface recomb, larger  $\Delta E_v$ , less recombination in emitter)
- Improved emitter-base ledge passivation
- Temp, Current density acceleration
  - midgap trap formation
  - hydrogen de-passivation
  - dislocation propagation
  - contact degradation, spiking
  - base dopant diffusion

$TTF = C J^{-\alpha} e^{(-E_a/kT_j)}$  C is const, J is current density,  $\alpha$  is current exponent,  $E_a$  activ. energy,  $T_j$  junct.temp.  $E_a$  typically ~1 eV  
(Henderson, 1995, Chen et al. Micro. Reliab. 45, 1869 (2005))

## Example of a 3D Approach to Device Reliability Issues- Stability Problems with GaAs/AlGaAs HBTs

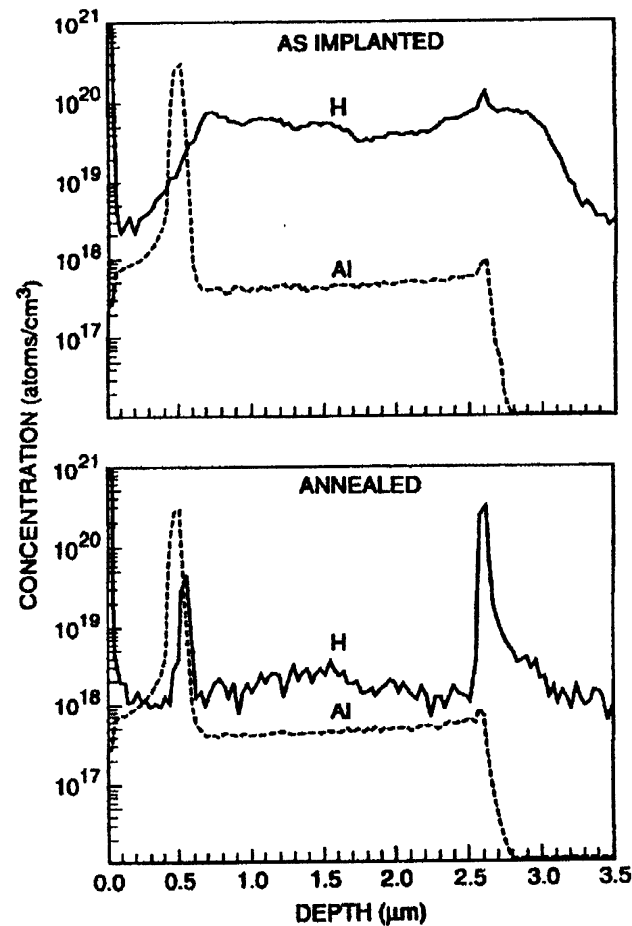
- High base doping, initially Be as the dopant
- At  $p > 4 \times 10^{19} \text{ cm}^{-3}$ , recombination-enhanced diffusion of  $\text{Be}^+$  interstitials from base into emitter, leading to positive shift in  $V_{\text{BE}}$  and decrease in gain
- Switch to C as dopant,  $p = 3\text{-}10 \times 10^{21} \text{ cm}^{-3}$  (still issues with metallization stability, surface passivation, avalanche breakdown)
- Implant isolation for maintaining device planarity

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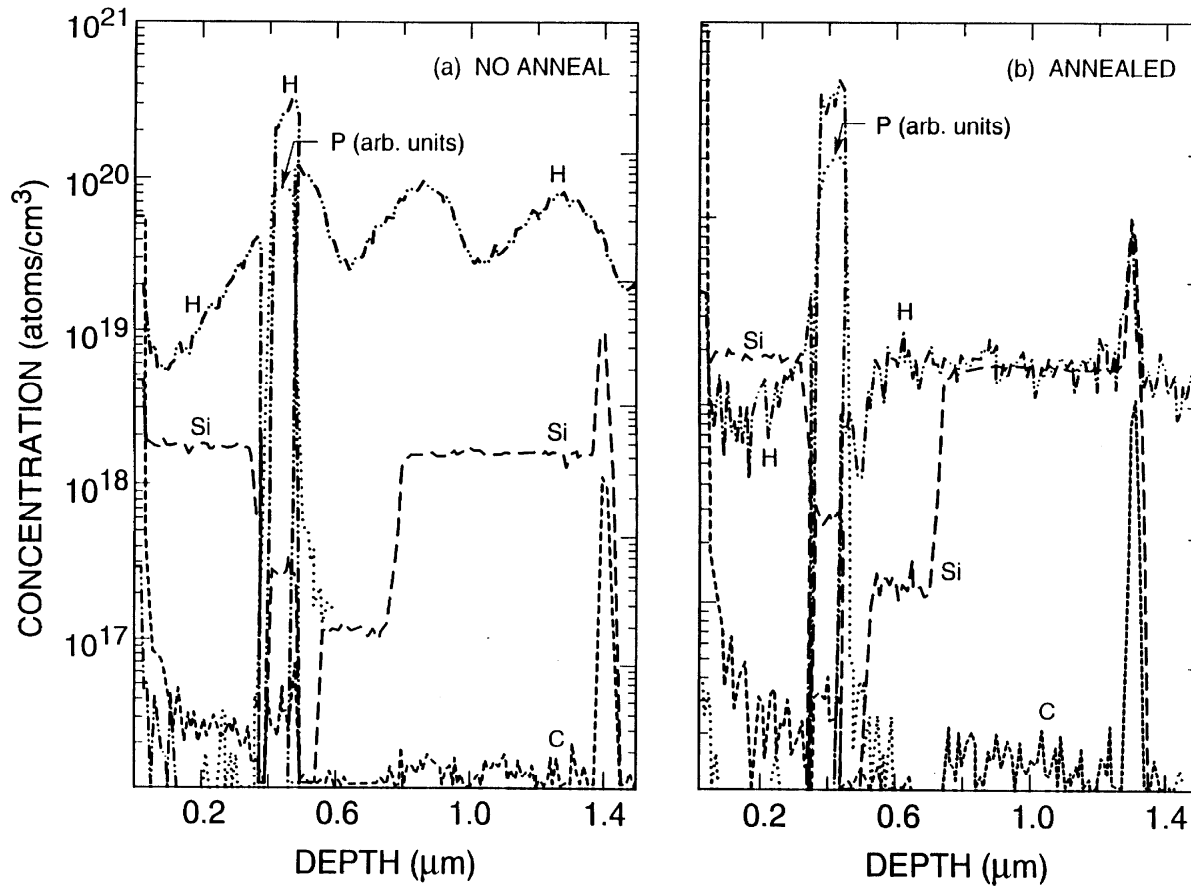


Implant isolation schedule

Species	Dose ( $\text{cm}^{-2}$ )	Energy (keV)
$\text{H}^+$	$3 \times 10^{15}$	100
$\text{H}^+$	$3 \times 10^{15}$	150
$\text{H}^+$	$3 \times 10^{15}$	200
$\text{H}^+$	$3 \times 10^{15}$	250
$\text{H}^+$	$3 \times 10^{15}$	300
$\text{H}^+$	$3 \times 10^{15}$	340
$\text{F}^+$	$8 \times 10^{12}$	40
$\text{F}^+$	$6 \times 10^{12}$	100
$\text{F}^+$	$7 \times 10^{12}$	200
$\text{F}^+$	$7 \times 10^{13}$	250
$\text{F}^+$	$8 \times 10^{12}$	300
$\text{F}^+$	$8 \times 10^{12}$	360



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# Example of a 3D Approach to Device Reliability Issues- Stability Problems with GaAs/AlGaAs HBTs

chuck temperature	Vcb	Power	junction temperature
202C	0V	15mW	261.7C
167C	0V	15mW	220.7C
127C	0V	15mW	174.1C
27C	4.5V	60mW	184.1C
27C	7.5V	90mW	301.5C

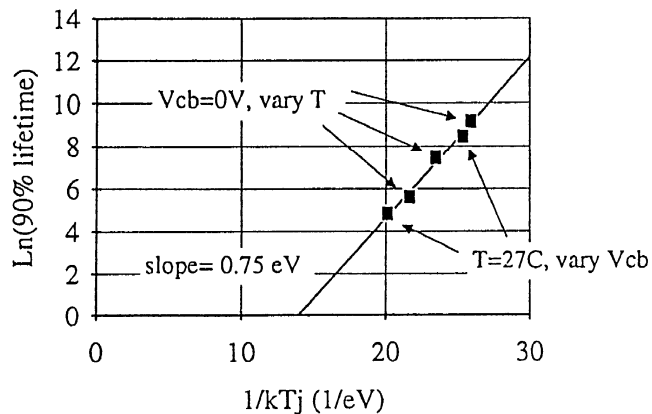


Fig. 1. Arrhenius plot of time-to-failure vs junction temperature. The time-to-failure  $t_{90}$  is defined as a 10% drop from the initial gain, corresponding to the initial degradation mechanism. The junction temperature is calculated for each stress condition, and is varied by changing the chuck temperature or the base-collector bias.

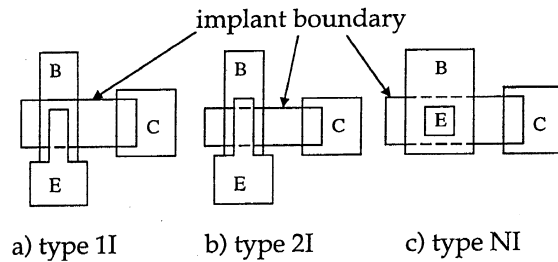


Fig. 2. Layout of test devices used to determine effect of implant isolation. Type 1I is the standard layout in which the implant boundary crosses the active area at one edge. In type 2I it crosses at two edges, and in type NI the implant is moved away from the active area.

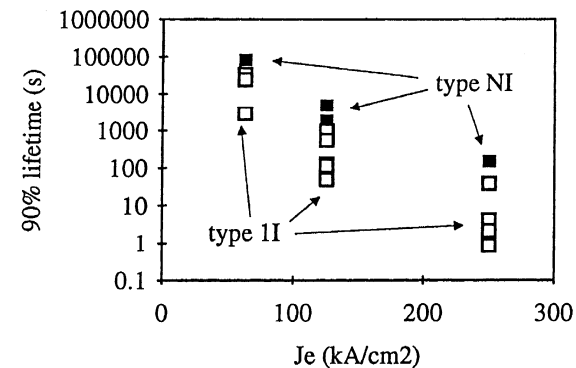
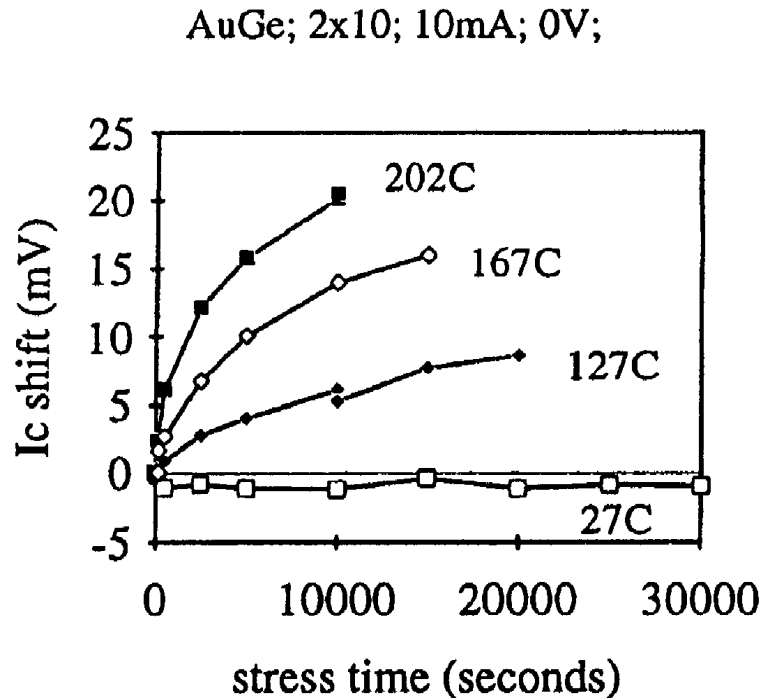
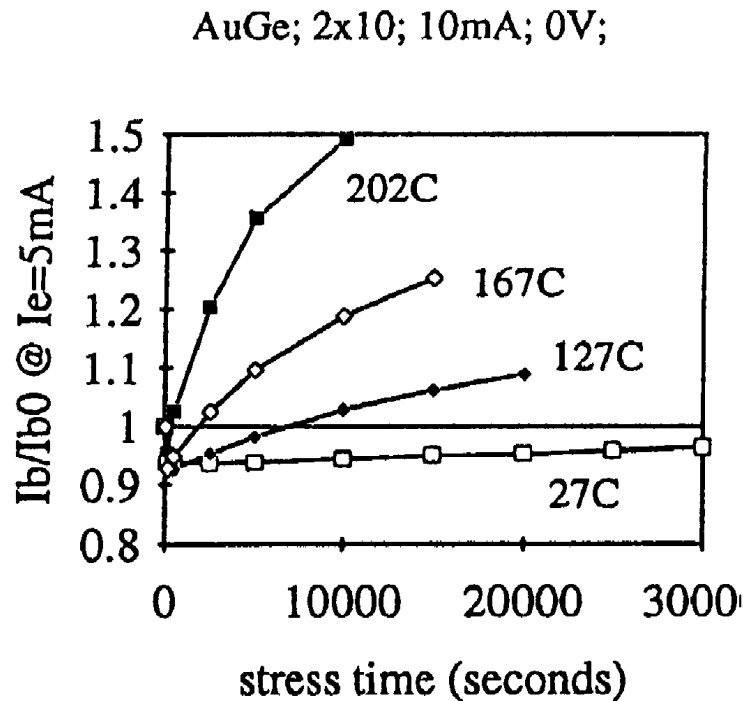
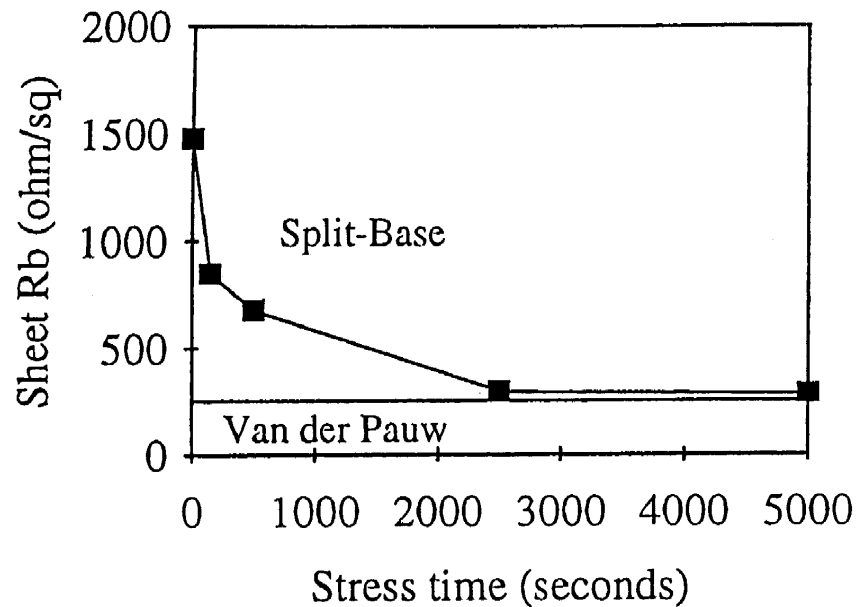
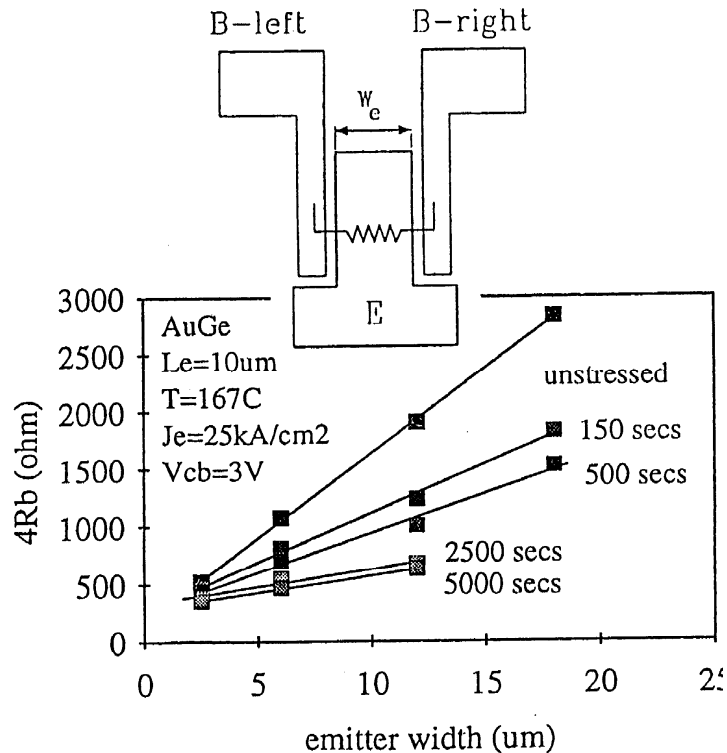


Fig. 3. Time-to-failure vs emitter current density for devices of type 1I and type NI, showing more stable operation for devices where implant is moved away from the active area. A common mechanism dominates the initial degradation in the range 50–250  $\text{kA}/\text{cm}^2$ .

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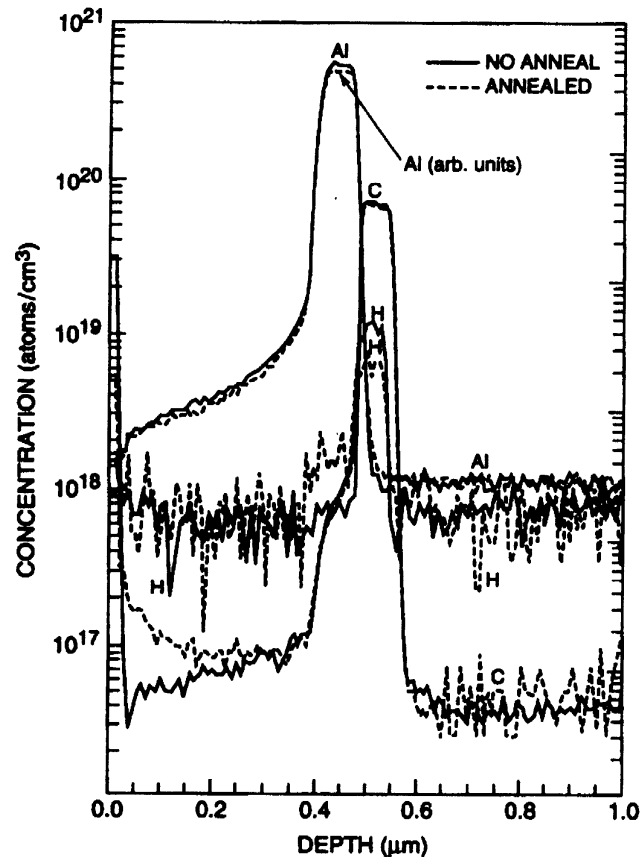
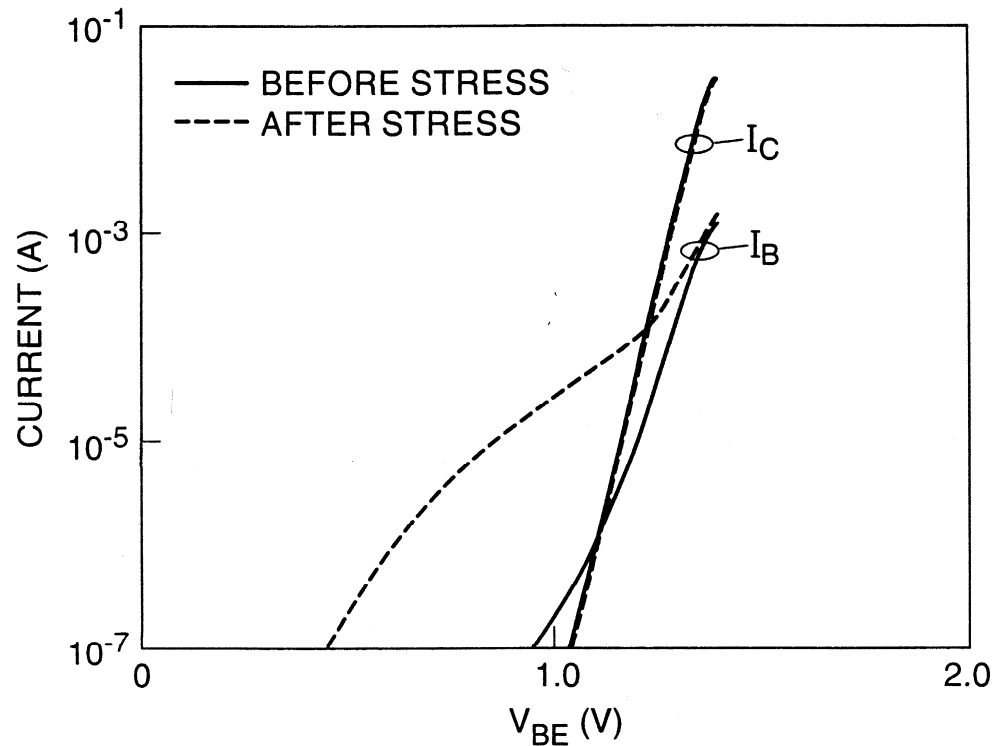


Fig. 1. SIMS profiles of H and C in hydrogenated and subsequently RTA (525°C, 5 min) annealed HBT structures grown by MOMBE.



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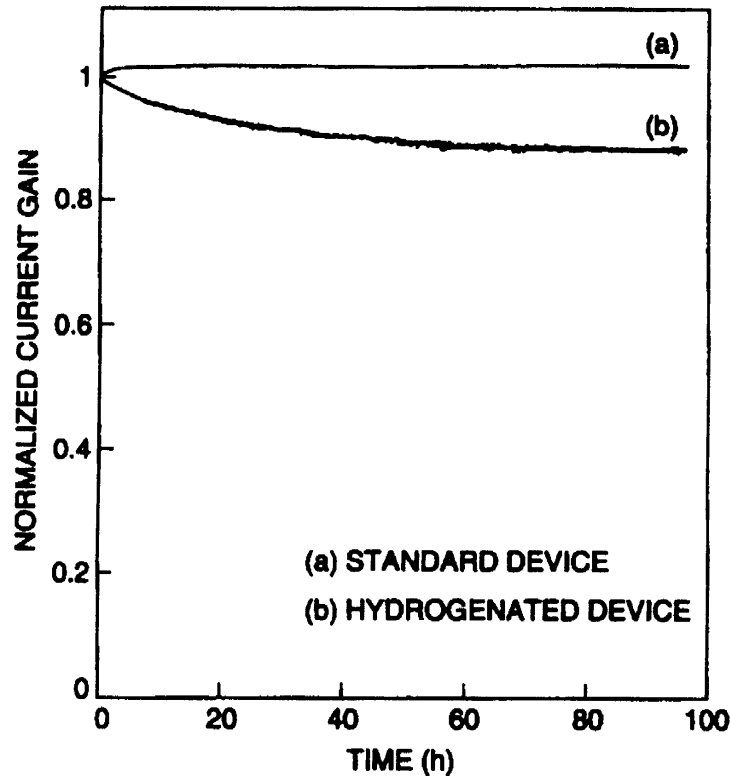
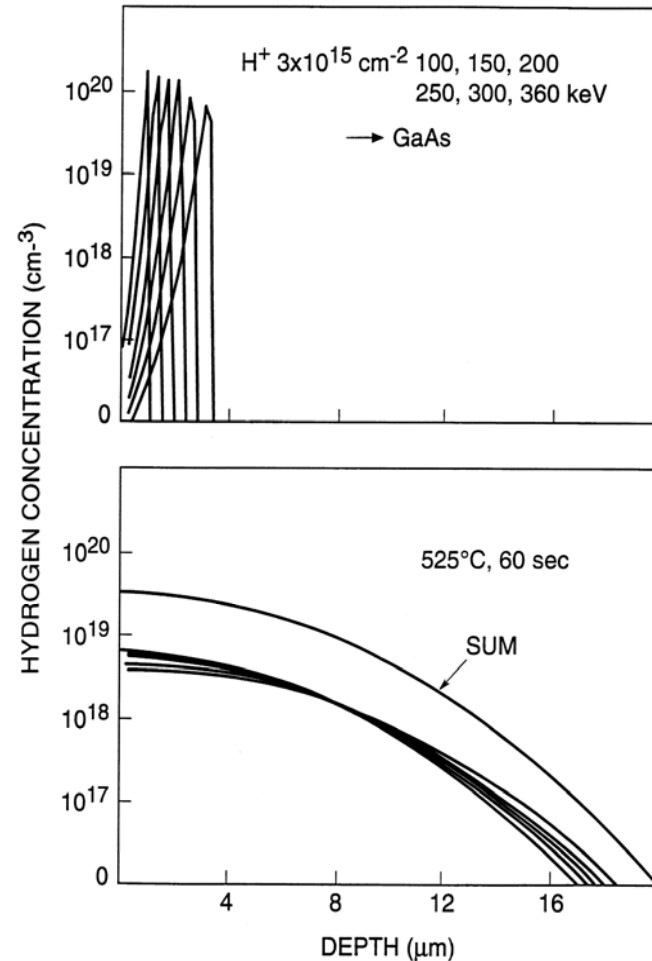


Fig. 2. Base current ( $I_c$ ) as a function of bias stressing time at a current density of  $8 \times 10^4 \text{ A cm}^{-2}$  for devices grown under standard or hydrogen-rich conditions. Annealed samples showed stable characteristics.



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- $(\text{C-H})^0 + e^- \rightarrow \text{C}^- + \text{H}^+ + e^-$
- Injection-enhanced reactivation of base dopants
- Atomic hydrogen may form molecules (inactive)
- $p$  increases, so gain decreases-dependent on injected current density and time

